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The State of Play

Can existing nuclear power stations be economically viable in a market increasingly dominated by zero short term marginal cost renewables and low natural gas prices? On that question the jury is still out – and will be for years to come. But the evidence indicates that a number of existing units have out-of-pocket costs that are greater than today's market prices.

Exelon, for example, has considered closing some of its units in northern Illinois:

> "We think the nuclear assets are very valuable," Mr. Crane [Exelon CEO] said. "We know how to run them better than anybody else. But at the end of the day, if we're not compensated for them

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we'll just have to shut them down." [1]

The combination of competitive market forces and artificial price suppression resulting from well-intended but poorly designed energy policies could force some highly efficient nuclear plants to shut down, threatening grid reliability and setting back efforts to meet the nation's carbon reduction goals, Exelon Generation President and CEO Kenneth W. Cornew said.

"The economic viability of these highly reliable, low-carbon generation sources is at risk, not because they can't compete in the marketplace, but because they can't compete when the playing field is uneven."[2]

'The economic viability of highly reliable, low-carbon nuclear resources is at risk, not because they can't compete in the marketplace, but because they can't compete when the playing field is uneven.'

Kenneth W. Cornew, Exelon Generation

Long a predator in corporate acquisitions free markets, Exelon appears ready to lay down with the lambs and request government intervention.

Exelon has long been a supporter of market reform. But as the markets are beginning to favor other players, Exelon has begun promoting options that would provide financial compensation for the environmental value of its low-carbon nuclear power.[3]

At the heart of the issue is whether nuclear generation will be viable in the emerging generation environment. Until a year ago, many of us would have found this a surprising question. The decision of Dominion Resources to close its Kewaunee nuclear station, and the ensuing Exelon statements, have changed that. Dominion's explanation was straightforward: It could not find a market for Kewaunee's output and could not sell the unit to a willing buyer.

Figure 1, on page 3, displays Federal Energy Regulatory Commission (FERC) Form 1 data on incremental costs of nuclear plants against an assumed market price based on a 7,000 Btu/kWh heat rate and the current EIA natural gas forecast. Obviously this is an approximation, since actual prices range from high on-peak to negative off-peak prices on occasion.

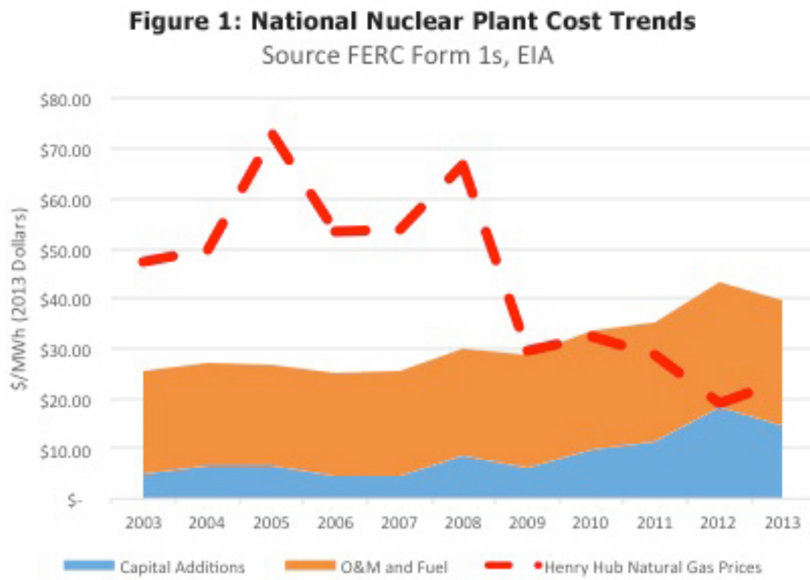
[1] Daniels, Steve. "What's Stronger than Nuclear Power? Falling Electricity Prices." *Crain's Chicago Business*. 18 Nov. 2014. Web. <http://www.chicagobusiness.com/article/20131116/ISSUE01/311169983/whats-stronger-than-nuclear-power-falling-electricity-prices>.

[2] Cornew, Kenneth W. *Exelon Calls for Energy Policy and Market Reforms to Ensure Clean, Reliable Energy Supply*. The Wall Street Journal. 14 Apr. 2014. Web. < http://online.wsj.com/article/PR-CO-20140409-912405.html>.

[3] Daniels, Steve. *Exelon warns state it may close 3 nukes*. Crain's Chicago Business. 03 Mar. 2014. Web.

<http://www.chicagobusiness.com/article/20140301/ISSUE01/303019987/exelon-warns-state-it-may-close-3-nukes>

Dr. Mark Cooper released a report last year identifying 37 nuclear installations representing 55 different reactors – over half of the U.S. nuclear generation fleet – as "at risk" plants.[4] He based his analysis on a variety of institutional factors such as past history, technology, and market structure. He added plant age as an additional significant factor.



Our study approaches the problem of nuclear viability from a different perspective – costs, as opposed to institutional factors like past history and technology. Since our available data comes from FERC's Form 1s, the comparison is restricted to plants under traditional regulation. We also restricted our sample to plants with continuous reports from 2003 through 2012 to apply a cross-sectional time series regression in order to calculate the impact of plant age on operating and incremental capital costs.[5] These results are reported below.

Our study has seven nuclear stations in common with Dr. Cooper's.[6] We have compared Argus' forward energy prices with forecasts of the plants from Dr. Cooper's analysis. For the period from 2014 through 2018, it appears that that a number of these plants' out-of-pocket operating and required replacement costs will exceed the cost of a replacement market source.

The situation is exacerbated by rising operations & maintenance (O&M) costs, as the U.S. nuclear fleet's age is an increasing factor.[7] Data from the Federal Energy Regulatory Commission indicates that both O&M and incremental capital addition costs are correlated with the age of the plant.[8]

In short, the industry appears to be entering a nuclear winter, with falling market revenues and increasing costs. This suggests that Kewaunee's fate may well be the first of a number of economically-based closures of nuclear plants.

[4] Cooper, Mark. *Renaissance in Reverse,* at 24-25.

[5] The regression statistics are available by email request sent to robert@mresearch.com

[6] Callaway, Diablo Canyon, Fermi, Monticello, Prairie Island, Quad Cities, and Wolf Creek.

[7] O&M costs are the daily non-fuel costs of keeping a plant up and running.

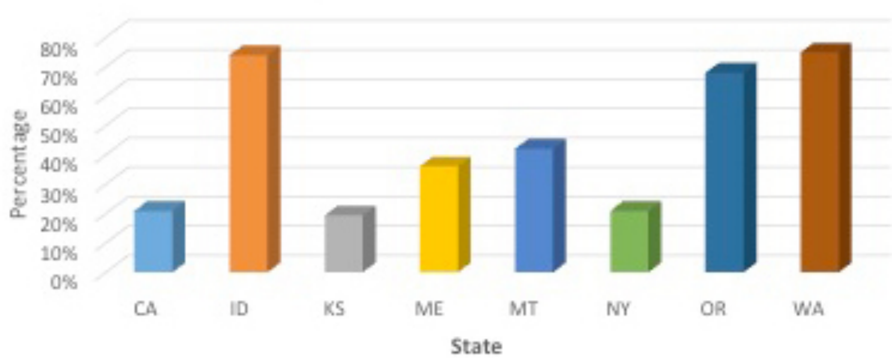
[8] The FERC Form 1 provides detailed information on O&M costs as part of the thermal plant reports starting on page 402. Incremental capital additions are identified on page 204

Nuclear Energy as a Price Taker

The nature of a non-dispatchable resource be it hydro, wind, solar, or nuclear, is that the energy must be sold at any price. This is one of the reasons why constrained areas such as the Pacific Northwest's Mid-Columbia market have increasingly been seeing negative prices during spring and early summer when hydroelectric and wind generation are high.

During hours when renewable generation is high, competition to find a load is increasingly intense. And as mandated renewable generation increases under state renewable portfolio standards, the amount of capacity with zero short-term marginal costs is increasing sharply. The Pacific Northwest has long possessed a large share of low-cost or zero marginal cost resources. Now other parts of the U.S. – principally the wind belt of the Great Plains, which stretches from Montana to Texas – are rapidly catching up. **Figure 2** depicts the situation for several of these states.

Figure 2: Percentage of Zero Marginal Cost Generation



As the proportion of generation that has zero or low short-term marginal costs increases, the tendency is for the short-term market price to fall. In the Pacific Northwest, where the proportion of hydro and wind is quite high, it is not unusual for off-peak prices to fall below zero.

Nuclear units have unusually high operating costs – especially at the critical decision point surrounding restart after refueling. This can bring the economics of nuclear into sharp conflict with current low market prices.

Nuclear Generation's Operating Costs

For decades the utility industry, its critics, and regulators have focused on the cost-effectiveness of constructing new nuclear plants. Today, the question has shifted to the cost-effectiveness of continuing to operate many existing nuclear plants. Many of today's plants appear unable to complete in markets that are dominated by renewables and inexpensive natural gas-fired generation. If that is indeed the case, Kewaunee may be the first of a number of nuclear plant closures that are based on economics of operating costs rather than the expense of replacement when a major plant component fails.

The traditional economic model of electric generation is deceptive. Industry sources ranging from the Energy Information Administration (EIA) to the Nuclear Energy Institute (NEI) can be misleading when it comes to determining the cost of nuclear plant operations.[9,10] These two sources agree that the operating cost of a nuclear plant – in 2012 prices – should be in the range of $11.8/MWh (EIA) to $23.0/MWh (NEI).[11] The reality is much different. The Columbia Generating Station, which provides an estimate of its production costs as part of its Ten Year Plan, cites an entirely different figure – $47.3/MWh.[12] Obviously, both sets of figures cannot be correct.

The traditional economic model holds that capital investment considerations become unimportant after a plant's in-service date. Ongoing costs are supposed to be treated simply as O&M and fuel. Dispatch decisions are based on variable O&M and fuel costs. This is not a bad model for natural gas and coal projects but it is a poor one for nuclear projects, which require sizable – and increasing – capital investments in many years.

Nuclear also has an eight- to ten-year fuel cycle –causing spot fuel prices to have less significance in the short-term – a factor that is poorly appreciated by most analysts. A specific unit may have long-term contracts ranging from yellow cake, to uranium hexafluoride, enrichment, and, finally, fabrication. Nuclear fuel commitments are often made years in advance. In practice, this means that long term contracts and unique fuel requirements for specific units drive fuel costs and are effectively "sunk" years ahead of use.

The key to understanding this issue is that a nuclear plant's short-term marginal costs, such as O&M, are low – lower than the estimates from the EIA and the NEI. But a nuclear plant's intermediate- term marginal costs, such as from additional capital investments, are quite high – much higher than the estimates cited above.

Nuclear Fuel Costs

Nuclear fuel is a good place to start. A nuclear plant's fuel requirements are complex and require substantial advance planning. The basic steps are mining, milling to yellow cake, conversion to UF6, enrichment, and fabrication. The first four steps are basically commodities. The fabrication step is unique for each plant. After fabrication, the fuel rods are inserted into the reactor during each refueling cycle. At any given time, a reactor will contain fuel rods from three refueling cycles. The costs identified by FERC and reported in FERC Form 1 are the amortized cost of the capitalized value of the fuel cycles currently in the reactor.

While the methodology of determining nuclear fuel costs may make good accounting sense, it has little or no resemblance to the actual per-kWh cost of fuel used in natural gas and coal units. If a coal unit is not dispatched, the coal is not

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9 http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

10 http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Costs-Fuel,-Operation,-Waste-Disposal-Life-Cycle/US-Nuclear-Industry-Production-Costs-by-Quartile

11 The EIA estimate can be found at http://www.eia.gov/forecasts/aeo/assumptions/pdf/table8_2_2014er.pdf. The NEI estimate can be found at http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Costs-Fuel,-Operation,-Waste-Disposal-Life-Cycle/US-Electricity-Production-Costs-and-Components.

12 http://www.energy-northwest.com/whoweare/finance/Documents/Energy%20Northwest%202013%20Annual%20Report.pdf, page 40.

burned but is available for later use, or even, in rare cases, for sale to another generator. The market price of coal is a suitable variable in the calculation of the plant's marginal cost. The same is true for natural gas prices.

The marginal cost of fuel for a nuclear plant is not a factor in plant owners' short-term decision-making in most cases, since the refueling cycle is inflexible in the short-term. Refueling cycles can be marginally adjusted, but obviously cannot be adjusted to allow economic dispatch of the unit. Moreover, the existing fuel cannot be sold. Any fuel that has entered the fabrication stage is effectively committed to a particular plant. The overlapping tiers of fuel already in the unit also complicate any possible marginal dispatch calculation, since only one-third of the fuel is "spent" in each refueling cycle.

Figure 3: FERC Form 1 Fuel and Market SWU Prices

Operationally, a decision to close a nuclear station will not allow recovery of the existing fuel in the unit, nor the fuel in fabrication but will allow sale of fuel components at earlier stages of the nuclear fuel cycle. Economic decisions relating to the market value of nuclear fuel components may be made up to, but not including, fabrication. Future operating decisions for nuclear plants have a great deal in common with driving a supertanker. Decisions are made years in advance and sudden shifts in course are next to impossible.

The marginal cost of fuel at the start of each refueling cycle is the upstream cost of nuclear fuel components that have yet to be purchased for future refueling cycles. Thus the EIA and NEI fuel cost estimates noted above are appropriate only for long-term decision-making and have no impact on short-run marginal cost.

Commodity fuel costs have fallen precipitously since 2008. A major component, the Separative Work Unit (SWU), is the commodity reflecting the enrichment step in the fuel cycle. **Figure 3** shows the decline in SWU prices compared with fuel costs as reported in the Form 1s.

As the figure shows, the market prices for nuclear fuel have a lagging impact on fuel costs reported by the utility in the Form 1. The cost of nuclear fuel appears to be increasing, while actual fuel procurement cost is falling dramatically. Thus, the FERC Form 1 reported cost of fuel will tend to be higher than the actual intermediate marginal cost of fuel. In many cases, the FERC Form 1 data reflects fuel component purchases from past years, when prices were much higher than comparable prices today.

Capital Additions

While traditional accounting may overstate the cost of nuclear fuel as a marginal cost, the continuing high demand for capital additions, such as post-Fukushima retrofits and major part replacements, dramatically understates reported marginal costs.

The major difference between nuclear plant operations and the operation of fossil-fueled plants is the continuing need for capital improvements in the former for the current and following fuel cycles.

A significant component of the high operating cost for the Columbia Generating Station is the continuing capital additions required to keep the plant functioning. To this must be added plant modifications mandated by the Nuclear Regulatory Commission – in recent years the additional safeguards implemented following the Fukushima disaster, for example.

The Columbia Generating Station has a unique institutional framework that requires a detailed Ten Year Plan be provided on an annual basis. The current plan has budgeted amounts ranging from $49.7 to $83.4 million per annum – in sum, $638 million through 2023.[13]

While the level of capital investment required to maintain an operating nuclear plant may seem high at the Columbia Generating Station, a careful review of plant in-service additions for nuclear equipment indicates that it is not unusual. In 2000, the Federal Energy Regulatory Commission added detail on nuclear plant capital additions to page 204 of the FERC Form 1. Restricting the analysis to the 24 plants with data available from 2002 to the present, the average yearly nuclear unit capital addition has been $98.1 million.[14]

While the marginal cost for hourly dispatch of a nuclear unit is effectively zero, the annual marginal capital requirement for a nuclear plant at the start of a refueling cycle is relatively high. In 2013, for example, fuel and operating costs averaged $24.8/MWh over the 24 plants in our Form 1 sample. The incremental capital additions averaged an additional $14.8/MWh. The total, $39.6/MWh, makes the decision to close the Kewaunee unit appear reasonable in many markets.

Simply put, when a plant owner reviews the economics of restarting a nuclear plant, it will consider both the short-term operating costs and the yearly capital additions. The Form 1 data also indicates that over the study period, the per-MWh cost of capital additions has been increasing rapidly.

Our research suggests that plant age, rather than technology, is the principal reason for these higher capital addition costs. The Fukushima disaster has focused industry attention on the Boiling Water Reactors (BWRs) as the Nuclear Regulatory Commission has ordered plant modifications that reflect lessons learned from Japan. Surprisingly, the statistical evidence suggests that BWRs are not more likely to have higher

13 http://www.energy-northwest.com/whoweare/finance/Documents/Official%20Blue%20Book%20LRP_Rev%200[1].pdf

14 Unlike other thermal plants, additional investment in nuclear is relatively constant. Each year brings new costs connected with safety, replacement, or better technology.

capital additions over time than Pressurized Water Reactors (PWRs.)[15]

The statistical results from the time series cross sectional regressions are very significant. The age variable is significant at the 99% level for both production costs and capital additions, implying a high probability that these costs increase with the age of a nuclear plant.

Capital additions are inherently volatile, reflecting safety improvements, replacements, and new investments. The model indicates an increasing level of investment cost over time and is also significant at 99%.

The bottom line is that the best predictor of nuclear operating costs and capital additions is the plant's age. Older plants cost more and will continue to cost even more as they age.

A forecast based on the pooled time series cross-sectional model indicates that nuclear operating costs will remain high relative to natural gas prices for years to come.

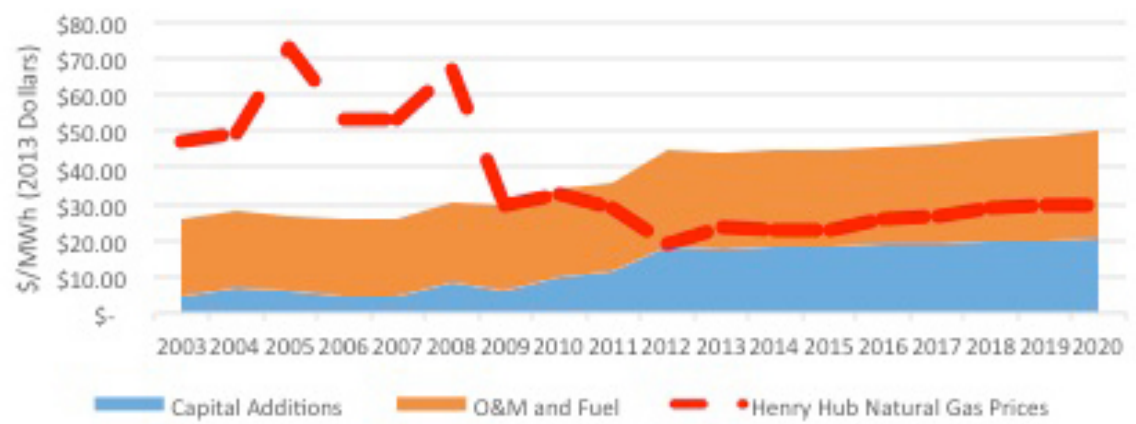
Added Factors Matter

Two additional factors need to be considered in the competitiveness of nuclear plants in the current environment:

1. Long term waste storage options for used nuclear fuel are in complete flux. In November, a federal judge effectively eliminated the financial component of the Nuclear Waste Policy Act of 1982:

Figure 4: National Nuclear Plant Cost Trends Forecasted to 2020

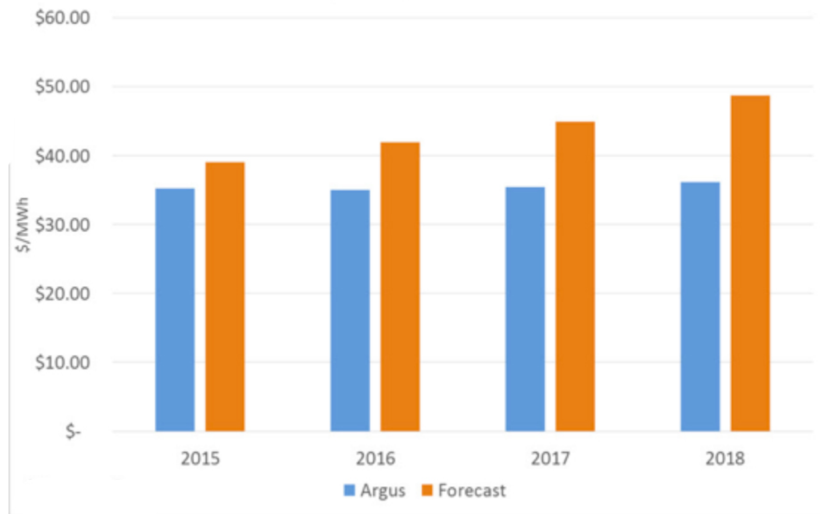
Source FERC Form 1s, EIA



[15] The statistical analysis shows that the choice of technology – PWR versus BWR – is not significant at the 95% level:

> Because the Secretary is apparently unable to conduct a legally adequate fee assessment, the Secretary is ordered to submit to Congress a proposal to change the fee to zero until such a time as either the Secretary chooses to comply with the Act as it is currently written, or until Congress enacts an alternative waste management plan.[16]

Figure 5: Quad Cities



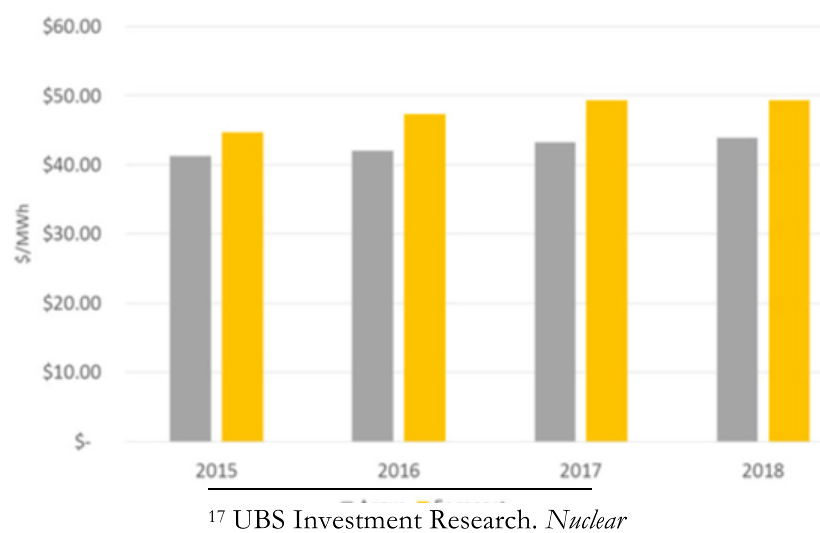
It is a very safe bet that any new plan to store nuclear waste is likely to be more expensive than Yucca Mountain and that new financing arrangements are likely to be significantly more expensive than the levels projected in 1982.

2. Decommissioning costs are also increasing rapidly. In a conference call a year ago, an NRC expert opined:

> "Historically, I would say that probably the minimum decommissioning funding formula has increased probably on average around 8% to 9% a year. The primary driver would probably be the burial cost. Disposal of low-level waste is getting to be a very expensive proposition for a variety of economic reasons. There are very few places you can dispose of this. There are also three major classifications for low level waste, such that the higher radiological content of the waste will incur higher costs for disposal."[17]

Our review of the underlying data supports this conclusion.

Figure 6: Diablo Canyon 1 & 2



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[16] United States Court of Appeals for the District of Columbia Circuit. *Order in NARUC v. U.S. Department of Energy No. 11-1066*. 19 Nov. 2013. Page 7.

[17] UBS Investment Research. *Nuclear Decommissioning Discussion with the NRC Staff: Conference Call Transcript*. Nrc.gov. 9 Apr. 2013. Web. 20 Sept. 2013. <http://pbadupws.nrc.gov/docs/ML1312/ML13128A305.pdf>.

Are the plants identified in Dr. Cooper's study competitive?

At each decision point for a nuclear plant, the question must be asked: Will refueling the plant be a cost-effective alternative to supply from the market?

Forecasting is always risky and forecasting nuclear plants is especially problematic. As noted above, seven of the plants in our sample were identified in Dr. Cooper's 2013 study as likely candidates for closure. These are Callaway, Diablo Canyon, Fermi, Monticello, Prairie Island, Quad Cities, and Wolf Creek.

Forward prices are quoted for many regions in the U.S. Our analysis used the most recent prices quoted in Argus US Electricity. The most recent market report included both peak and off-peak for calendar years 2015 through 2018. The values compared here are for energy only. Diablo Canyon reports no capacity revenues. In Illinois, Commonwealth Edison has voluntarily removed its unit from the capacity market.[18]

The highest cost units, Monticello and Prairie Island, are in Minnesota, which does not have widely accepted market prices. Callaway and Wolf Creek are also distant from major market hubs.

The Diablo Canyon and Quad Cities plants (**Figures 5 and 6**, on page 9) are appropriate candidates for comparison with forward markets. Diablo Canyon is located in central California, where forward prices are widely reported. This is also true for the Quad Cities unit that has figured prominently in the media as another candidate for closure.

Projections of O&M and incremental capital addition costs indicate both plants face considerable market pressure in the next few years, as **Figure 4**, on page 8, makes clear.

These comparisons are subject to many caveats, including the implicit uncertainty of forecast capital additions in the future and whether historical cost trends will continue. The market prices from Argus are actual market prices – achievable today.

Is Kewaunee the model for future plant closures?

Is Kewaunee the model for future plant closures? The answer appears to be "yes."

The problems facing the nuclear industry are national in scope and appear to be enduring in effect. Due to additions of more renewables with zero short-term marginal costs and continued low natural gas prices, nuclear stations, especially those near hubs with active trading, will face a challenge at each refueling cycle. At each such decision point the question must be asked: Will refueling the plant be a cost-effective alternative to supply from the market? Only a major change in the economics of the industry is likely to avoid market-based nuclear plant closures in years to come. □

[18] Naureen S. Malik and Jonathan N. Crawford. *Higher Power Costs in U.S. East as Regulations Squeeze Supplies.* Bloomberg, 13 May 2014.